Higgs to llγ at CMS (for discussion)

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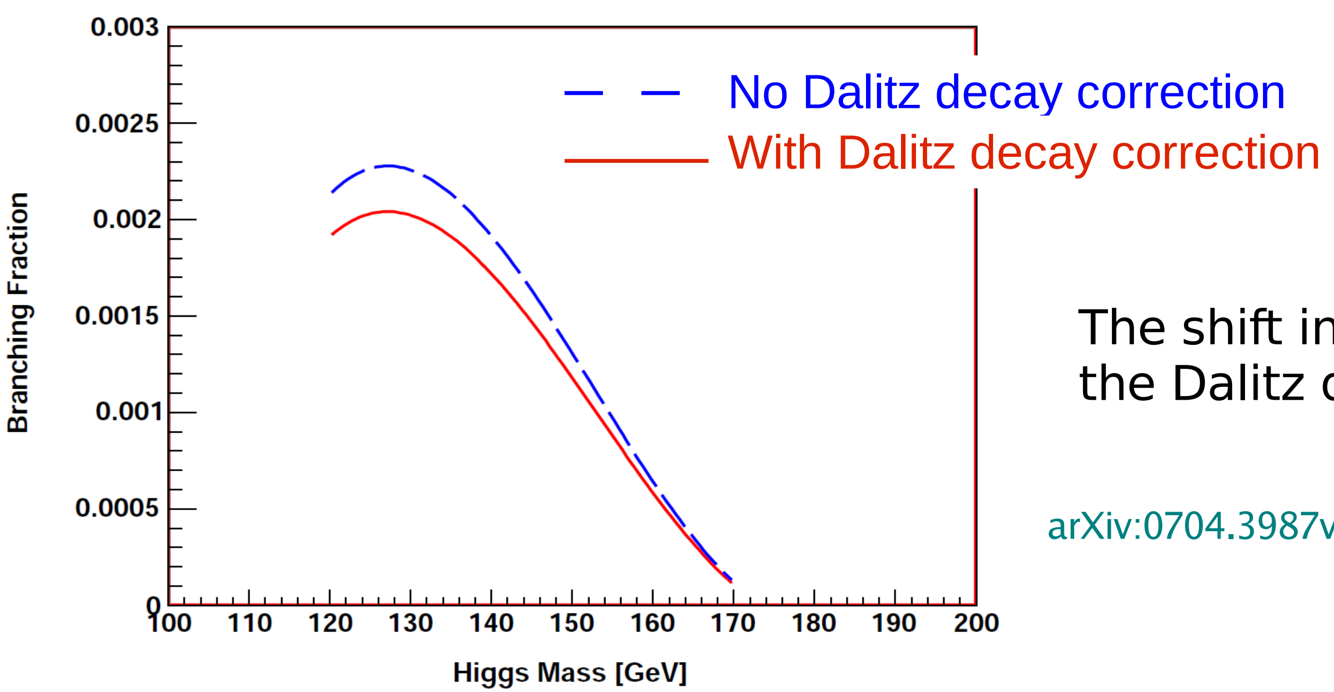
for CMS

Scope of the current discussion

1. Due to the short notice the views expressed are based on only few people from CMS working on H→Zγ analyses

2. There is a particular emphasis on low di-lepton invariant mass because
   1. the Higgs Dalitz decays are best distinguished there
   2. there is no supported MC simulation for these
   3. there is an on-going experimental effort in this region depending a lot on theoretical input



The shift in the Br(H→$\gamma\gamma$) due to the Dalitz decay correction.

arXiv:0704.3987v2 [hep-ph]

H→llγ theoretical inputs

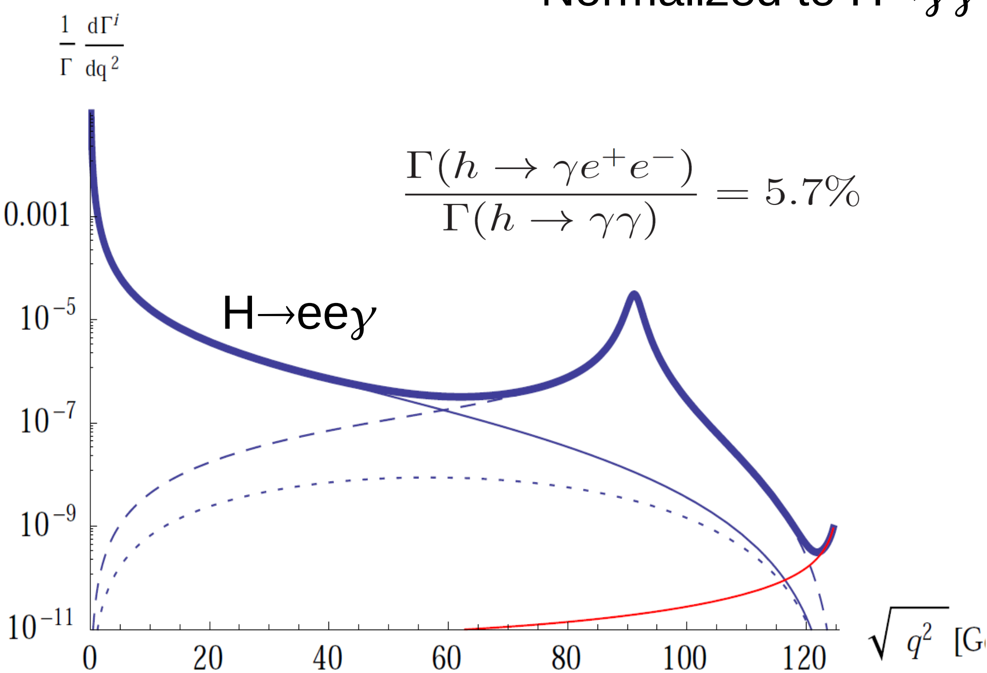
For a SM Higgs of M=125 GeV there are the following assumed facts (LHC@8 TeV)

Muon modes:	H→Zγ/H→γγ	H→Zγ/H→ZZ	H→Zγ/H→μμ
rate ratio	**2.3×10^{-2}**	**1.7 (only Z→μμ)**	**0.24**

X $(A\epsilon)_{H\to Z\gamma}/(A\epsilon)_{REF}$

Production cross-section of **H→Z(μμ)γ**: ~1.0 fb

Normalized to H→γγ differential decay rates



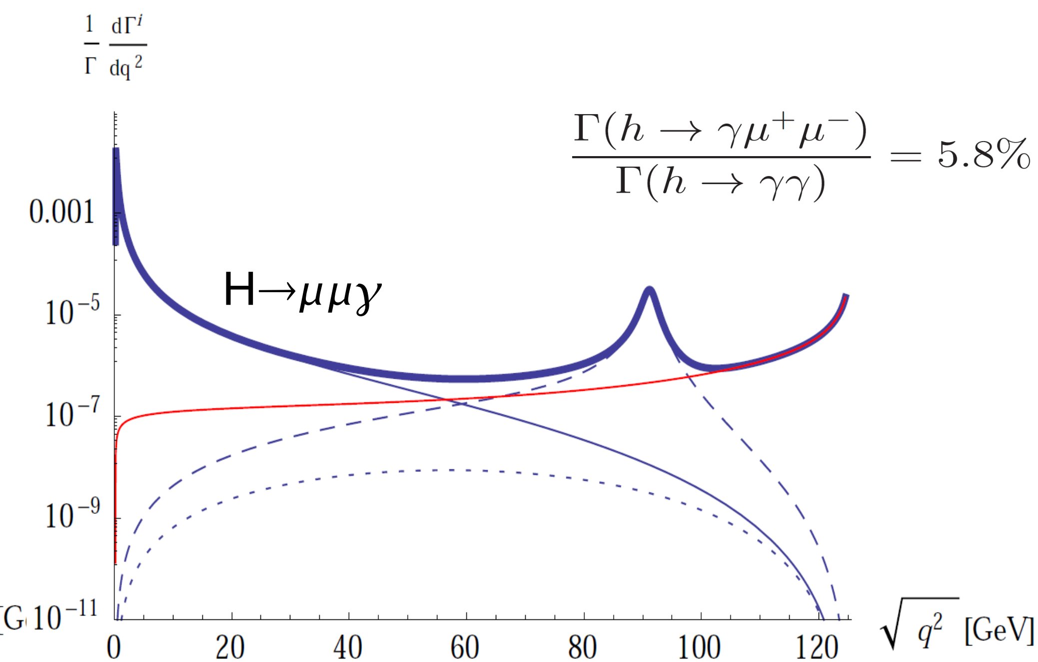


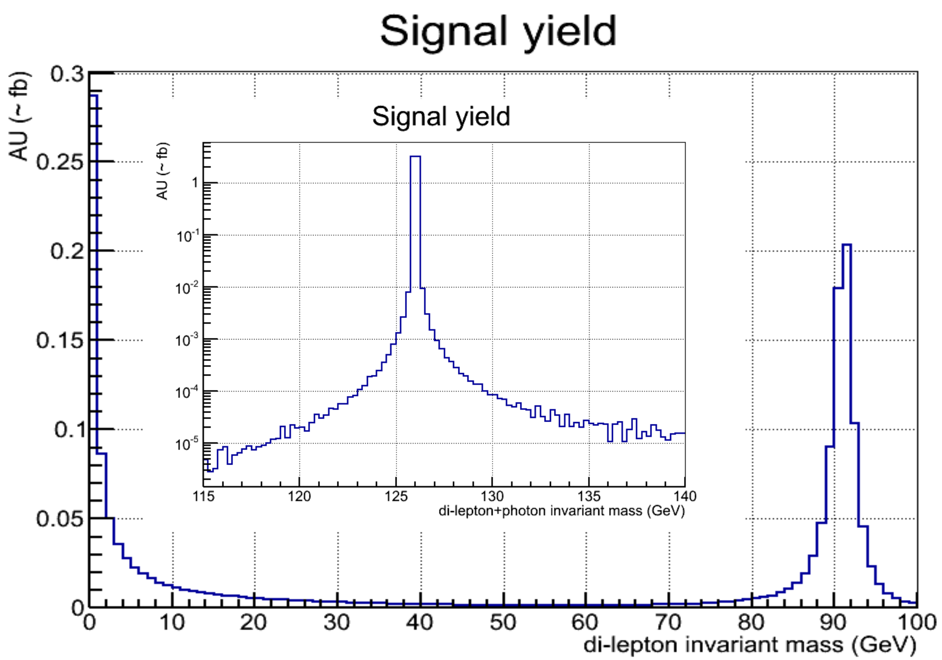
Figure 4: The invariant mass distributions of $h \to \gamma e^+e^-$ normalized by $\Gamma(h \to \gamma\gamma)$. The red line denotes the contribution of the tree diagrams, the thin solid line denotes the contribution from the γ^* pole diagrams, and the dashed line the contribution from the Z^* pole diagrams while the thick line gives the total contributions. The dotted line denotes the contribution from the four-point box diagrams.

arXiv:1303.2230v1 [hep-ph]

$H \to ll\gamma$ in MCFM

Higgs Dalitz decay is **simulated in MCFM*** (no detector effects!) with a mass of 126 GeV @8 TeV center-of-mass.

There are limited number of cuts applied (min[M(ll) = 300 MeV]) and there are various constants used I will not list (QCD factorization and renormalization scales are set at 50 GeV, PDF set is CTEQ6M, ...).



Roughly half the $H \to ll\gamma$ events come from below the Z peak

Z/γ^* mass range (GeV)	60-120	50-120	0.3-50	0.3-20	0.3-5	0.3-2	0.3-1
σ, fb	**0.881**	**0.896**	**0.741**	**0.653**	**0.487**	**0.373**	**0.289**
Fraction in % (wrt 0.3-120 GeV)	**54**	**55**	**45**	**40**	**30**	**22.5**	**17.5**

* http://mcfm.fnal.gov/

$H \to ll\gamma$ in the CMS experiment

- $H \to \gamma\gamma$
  - although conversions (to ee) are allowed they are cut out if they originate from inside the beam pipe
  - thus no genuine $H \to ll\gamma$ events can survive (in first order)

- $H \to Z\gamma$
  - we investigate the Z decaying to light leptons
  - the di-lepton invariant mass is studied above 50 GeV
  - thus the rate is dominated by the Z pole (as we would like for this study)
  - still –virtual contributions change the rate (of $H \to \gamma\gamma$ as well)
  - there is small contamination from $H \to \mu\mu$ (predominantly FSR)

- Higgs Dalitz decays
  - there is an on-going effort to study the di-lepton invariant mass spectrum below 50 GeV
  - we have proper high-efficient triggers for the muon channel
  - we still have to asses the plausibility of studying other channels (electrons, quarks)
  - overall –the current lack of supported MC simulation does not help

- Drell-Yan contamination
  - the main backgrounds come from Drell-Yan + photon (jets) events
  - these could be both FSR or ISR events
  - there is likely sizable $pp \to \gamma^*\gamma$ (correction to DY) contamination at low $M(\gamma^*)$

H→Zγ in the CMS experiment

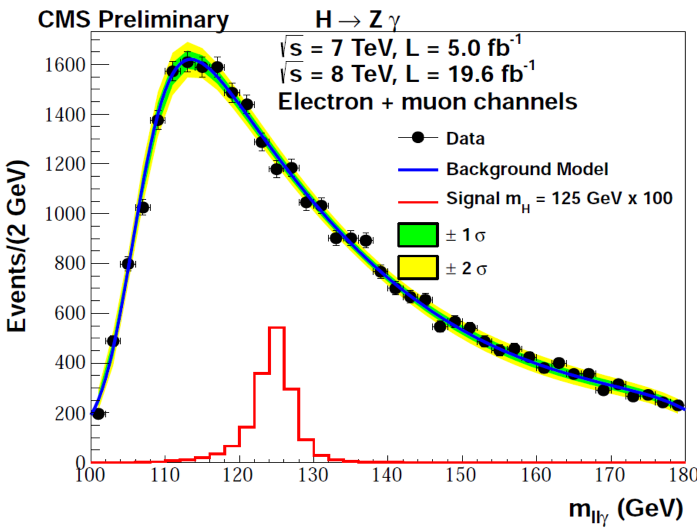


Table 1: Luminosity and observed data yields used in the analysis. Expected signal yields for a 125 GeV SM Higgs boson.

Sample	Luminosity (fb^{-1})	num. of events $100 < m_{\ell\ell\gamma} < 180$ GeV	num. of events $120 < m_{\ell\ell\gamma} < 150$ GeV	num. of events predicted for $m_H = 125$ GeV
2011 ee	4.98	2268	1041	1.2
2011 $\mu\mu$	5.05	2739	1223	1.4
2012 ee	19.62	12482	5534	6.3
2012 $\mu\mu$	19.62	13392	5993	7.0

Figure 1: $m_{\ell\ell\gamma}$ spectrum in the electron and the muon channels for the 7 and 8 TeV data combined. Also shown is the expected signal due to a 125 GeV standard model Higgs scaled by 100 and the sum of the individual fits made to the data for each channel and event class.

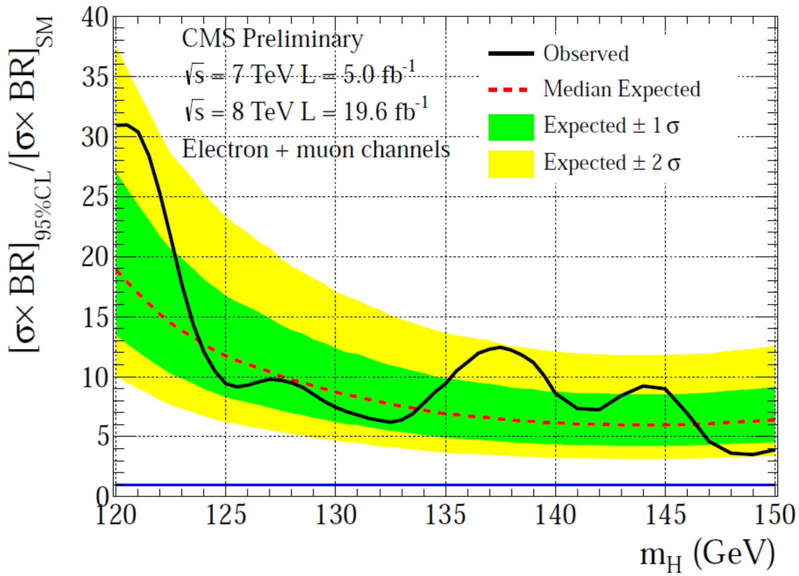


Figure 4: Exclusion limit on the cross section of a SM Higgs boson decaying into Z-boson and a photon as a function of the Higgs boson mass based on 5.0 fb^{-1} of data taken at 7 TeV and 19.6 fb^{-1} at 8 TeV.

Highlights from

CMS-PAS-HIG-13-006

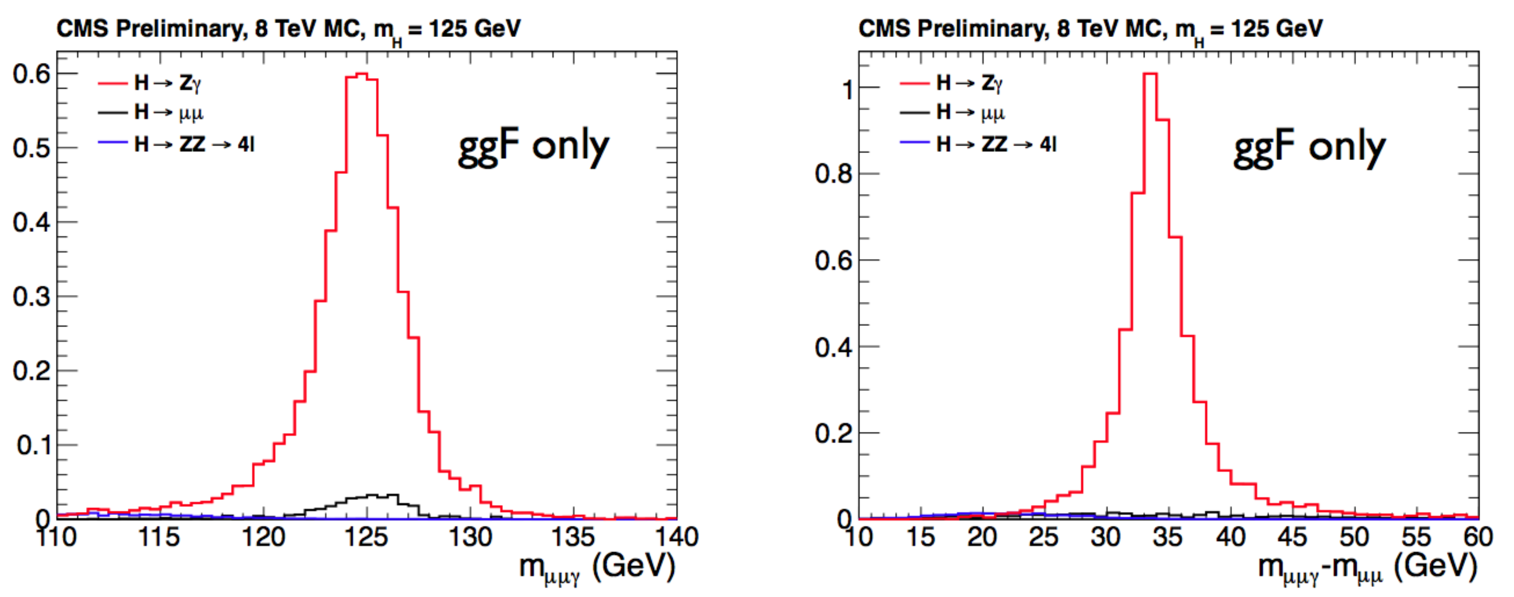
We are still only sensitive to rates exceeding the SM expectations ~ten times (at M(H)=125GeV).

Reminder: M(ll)>50 GeV

Contribution from $H \to Z\mu\mu$ to $H \to \mu\mu\gamma$

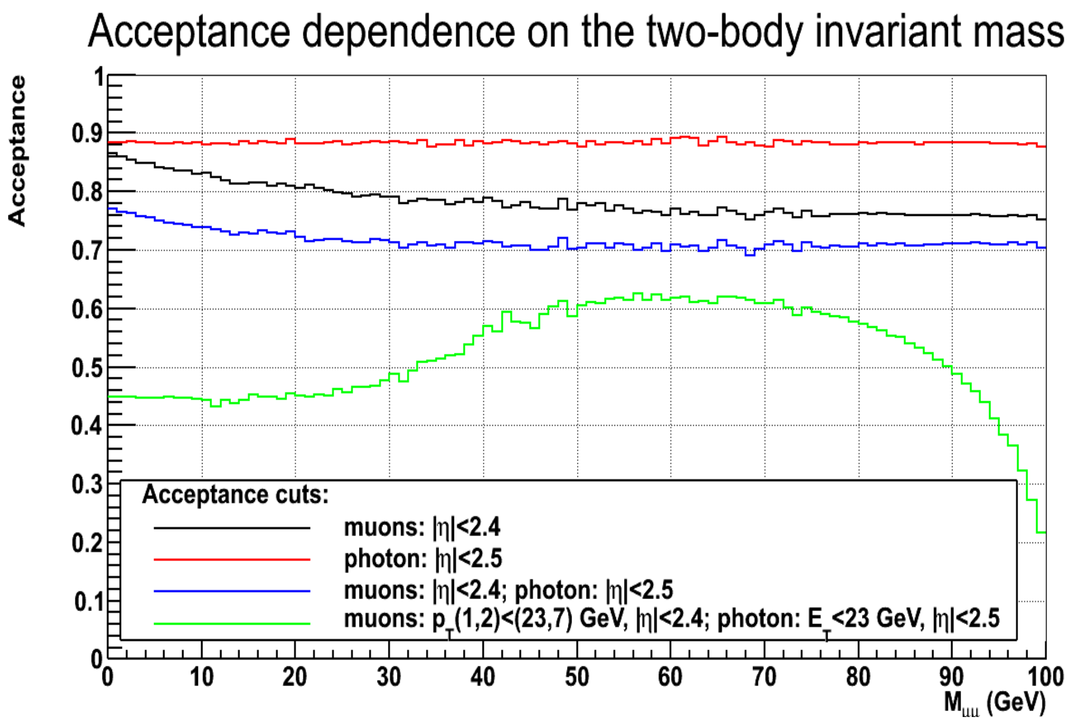
- BR of H→μμ @ 125GeV : 2.20E-04
- BR of H→Zγ @ 125 GeV : 1.54E-03
  - however, if we mainly look into H→Zγ→μμγ, BR becomes 5.18E-05

	ggF	VBF
H→Zγ	6.10	0.51
H→μμ	0.34	0.03
H→ZZ	0.20	0.02



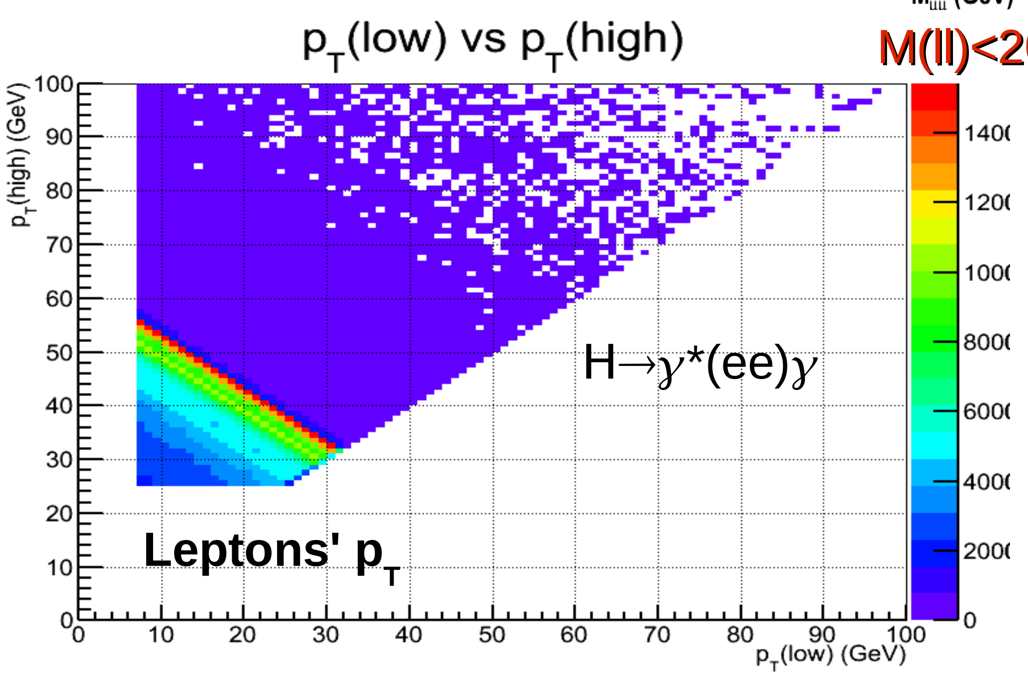
Features of H→llγ (plausibility for measurements)

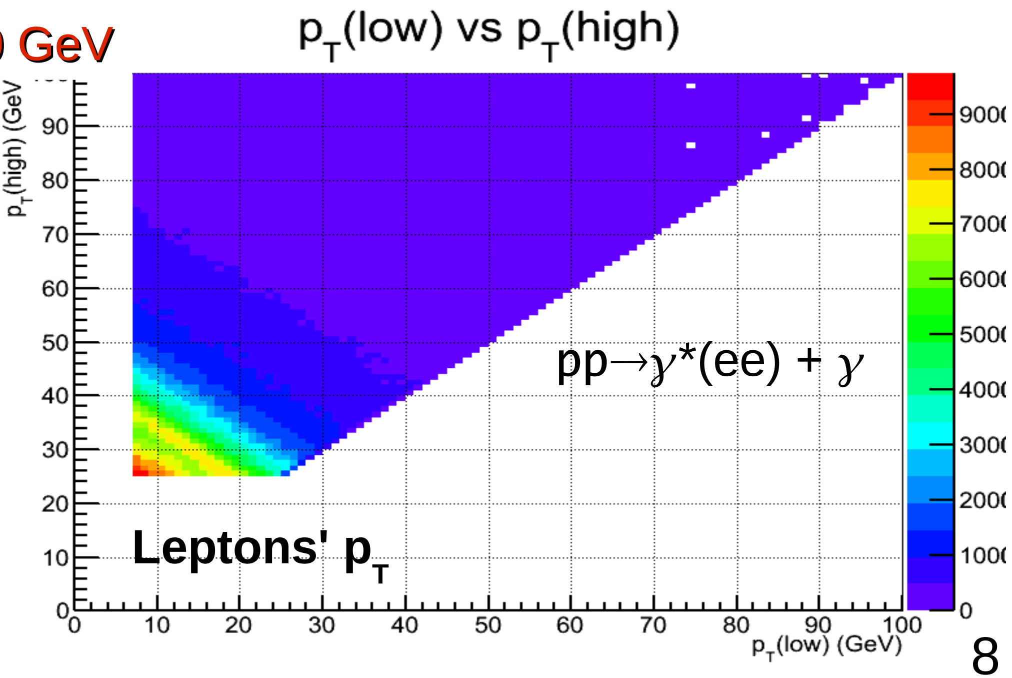
MCFM studies



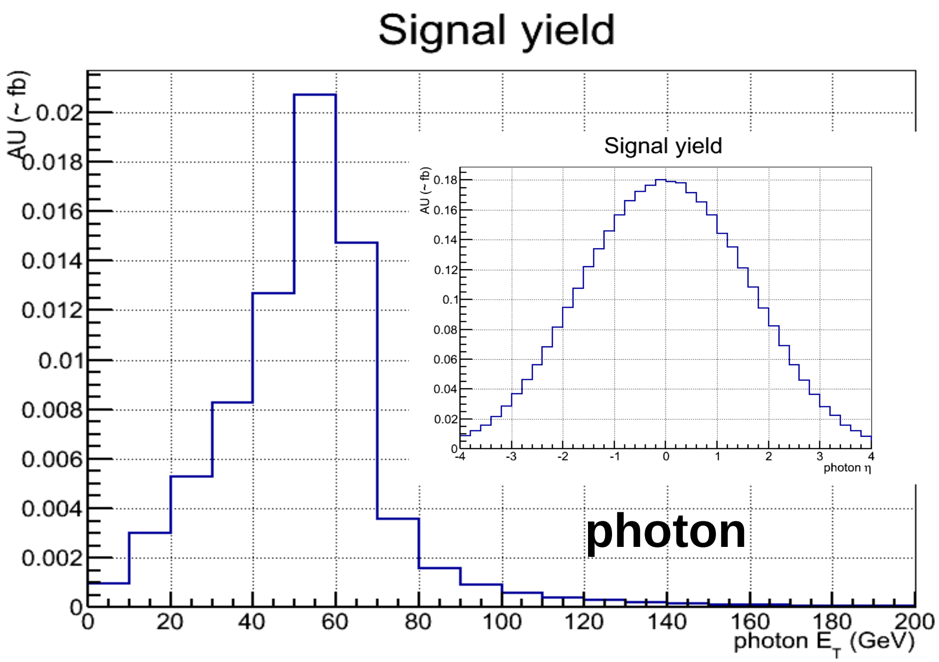
Geometrically only 20-30% of the events are lost. Depending on the kinematics cut we could keep most of the remaining events.

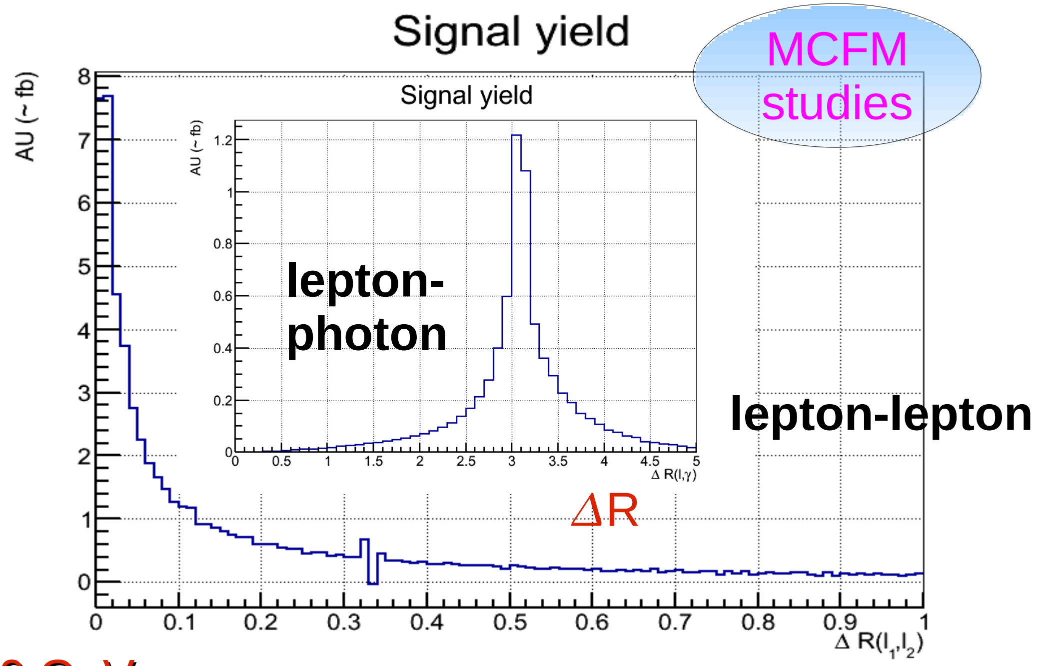
M(ll)<20 GeV



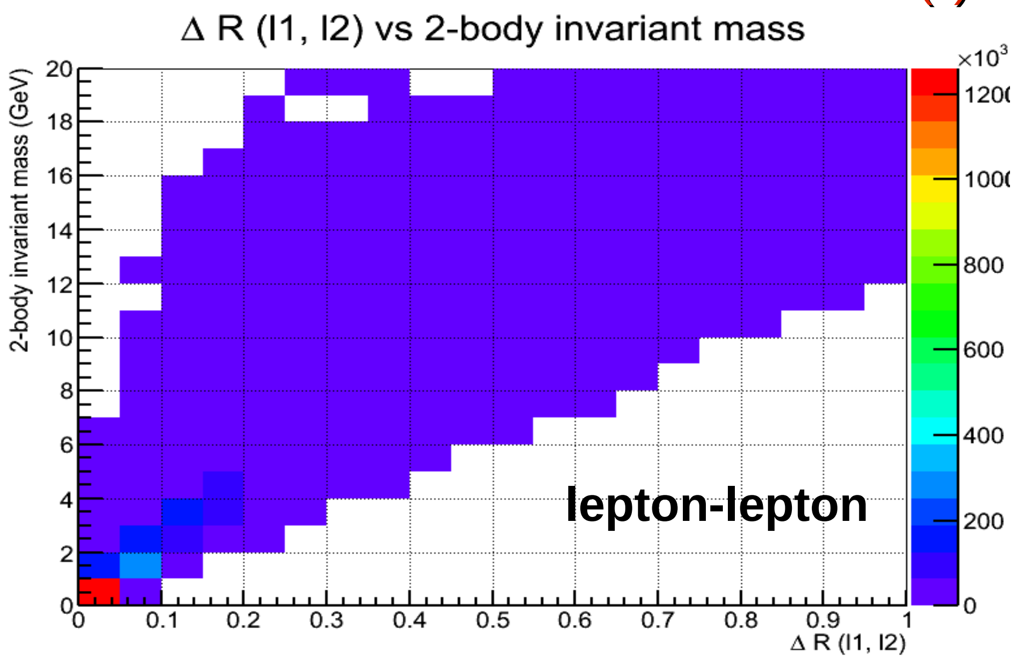


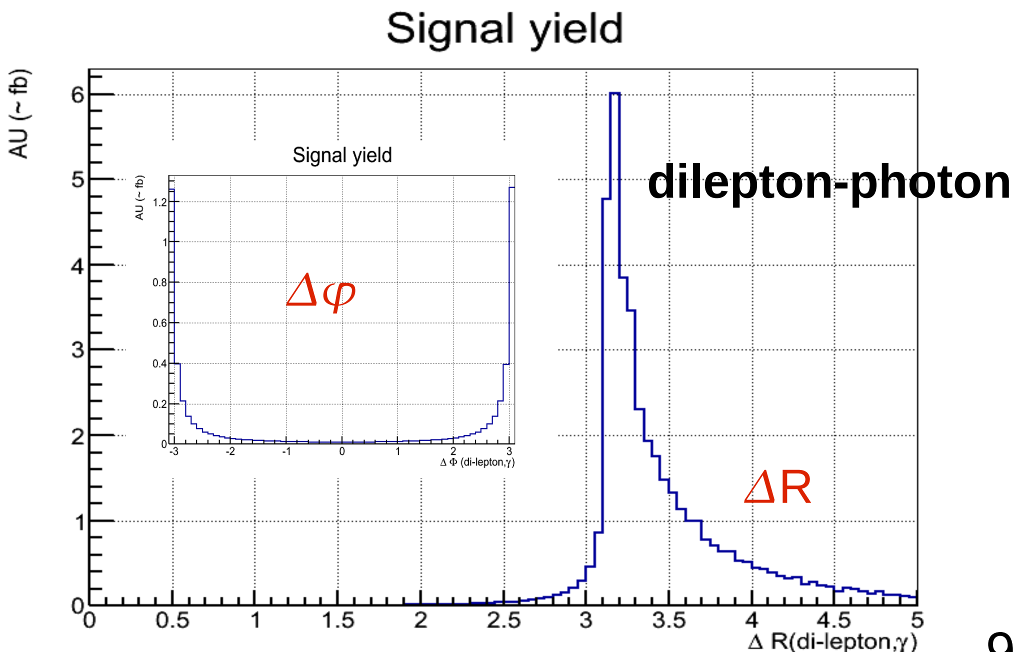
Features of H→llγ (plausibility for measurements) /2/





M(ll)<50 GeV





Features of H$\rightarrow$llγ (plausibility for measurements) /3/

- At low di-lepton invariant masses the photon is relatively energetic and back to back to leptons (fermions)
  - good resolution
  - well separated from other objects

- The separation of leptons depends (linearly) on their invariant mass
  - they are on top of each other (at IP!) at zero mass
  - experimentally they are still distinguishable as studies on data and MC show for muons – the efficiency is also high, at least 80%
  - electrons and jets may be more problematic (at least at very small masses)

- At high invariant masses (around the Z pole) only the rate wrt to “pure” H$\rightarrow$Zγ is changed and we do not expect any other currently observable feature

(with more data this may be reconsidered)

... and $H \to qq\gamma$

- The Dalitz mode is active for all fermions
  According to arXiv:0704.3987v2 [hep-ph] approximate branching fraction ratios are:
  electron : muon : tau : u/d/s/c : b - 4 : 2 : 1 : 5 : 0.2

I will not comment on consistency with latest (lepton mode) results but will just emphasize that quark contributions can be substantial (which may be of direct experimental interest too).

- Another point is related to the low-mass resonances: $H \to V\gamma$ with V = J/ψ or Υ
  Very recent calculations by Geoff Bodwin and Frank Petriello * show the following (@8TeV)

BR_{direct} $(H \to J/\psi\ \gamma) = 1.4 \times 10^{-7}$ $BR_{indirect}$ $(H \to J/\psi\ \gamma) = 1.6 \times 10^{-5}$

BR_{direct} $(H \to \Upsilon\ \gamma) = 6 \times 10^{-7}$ $BR_{indirect}$ $(H \to \Upsilon\ \gamma) = 1.4 \times 10^{-6}$

direct production: proceeds through the HQQbar coupling

indirect production: proceeds through $H \to \gamma^*\gamma$ with the subsequent transition $\gamma^* \to V$

$BR_{indirect}$ $(H \to J/\psi(\mu\mu)\ \gamma) = 1.1 \times 10^{-6}$

BR_{cont} $(H \to \mu\mu\gamma) = 4.6 \times 10^{-7}$ $\leftarrow$ in the limit of $M(J/\psi)-0.1$ GeV$<M(\mu\mu)<M(J/\psi)+0.1$ GeV !

- The J/ψ contribution is not only sizable but the resonance peak should be visible over the continuum background –more relevant for 13/14 TeV running

* A note is being written but I am allowed to distribute the preliminary results for the sake of discussions. In the meantime please contact Geoff and Frank if you are interested in details.